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University of Cambridge
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The Production and Utilisation of Scots Pine in Great Britain

Part I.   Production

No. 1.   Sample Plots at Woburn

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CONTENTS

1—2

THE PRODUCTION AND UTILISATION OF SCOTS PINE IN GREAT BRITAIN

PART I. PRODUCTION

I. INTRODUCTION

THE present paper forms the first of a series, which the writers hope to publish at intervals, giving the results of their research work regarding the production and utilisation of the timber of Scots Pine in Great Britain.

OBJECTS OF THE WORK AND REASONS FOR SELECTION OF SUBJECT.

The main object of the investigation is to determine as closely as possible the potentialities of Scots Pine as a timber tree in this country, and to estimate the extent to which the timber, when grown under proper silvicultural management, is capable of taking the place of imported timber of the same class.

There were several reasons for selecting Scots Pine as the first subject of enquiry in the timber research work which was begun at Cambridge this year (1913). It is a tree which exhibits a wide range of variation in the structure and quality of its timber. The timber produced on the borders of the White Sea differs so greatly from that produced in say Prussia, that they might easily be taken for distinct species. A similar variation can be found in Scots Pine timber produced in different districts in Great Britain. This structural variation naturally exerts a considerable influence on the quality of the timber, the uses to which it can be applied, and consequently on its market value.

There is no definite information available as to the several factors which influence this variation in quality; thus the study of qualities characteristic of different districts, and the collection of information as to the soil, climate, aspect, elevation and silvicultural conditions under which each quality is produced, become matters of prime importance. It is also essential to the enquiry that the yield per acre obtainable under each set of silvicultural conditions should be ascertained, and yield tables prepared to shew the possible production of each quality of timber in the several localities.

In the attempt to appraise the influence of different factors on the structural variation of timber generally, the task is simplified by the selection of a coniferous timber, the woody elements of which consist solely of tracheids, in preference to a dicotyledonous timber. The latter may shew a wider range of variation, but its more complex structure renders the interpretation of any differences observed a matter of far greater difficulty.

The timber of Scots Pine further possesses an economic value greater than that of most other trees, on account of the multitude of uses to which it can be applied. It is the most important building timber, and immense quantities are used for sleepers, paving blocks, mining timber, pit props; telegraph, telephone, and scaffold poles; shipbuilding, fencing, and innumerable other purposes. This is evidenced by the large amount annually imported from the Baltic under a variety of names, "Red" or "Yellow Deal"; "Redwood"; "Swedish," "Norway" or "Baltic Fir"; "Northern Pine," etc.

It is again a tree which gives comparatively quick returns, and is especially suited for certain classes of poor soil where few other trees will grow. Many extensive areas of derelict land exist on which Scots Pine will probably prove the most suitable, if not the only suitable tree, to plant. Large areas of such land are to be found within easy reach of Cambridge, and, as our first studies will naturally be made in the eastern counties, we hope that the results may prove of special value for this district. Later on, when our investigations can be extended to other districts, such as the north of England and Scotland, where the tree is or can be extensively grown under very different climatic conditions, the comparison of results should yield information of considerable interest. Until reliable indications are available as to the results which may be expected from planting operations, it is unlikely that land owners will be induced to incur the outlay required for extensive afforestation work.

SCOPE OF THE ENQUIRY.

The problem naturally resolves itself into two main lines of enquiry, which must be approached by separate routes.

PART I. The first point to determine is the quality of timber produced under the varying conditions of soil, aspect, elevation, climate, and management; and the yield of each quality obtainable when the common laws of silviculture are applied.

The influence of each of these factors upon the structure must be studied, and an attempt made to correlate the production of different qualities with definite conditions of growth. This is mainly a silvicultural problem, the solution of which will, it is hoped, enable a series of British soil classes to be recognised, and also perhaps British timber grades.

PART II. The second part of the enquiry embraces studies in regard to the utilisation of the timber and the purposes for which these qualities are suitable. This involves the grading of British quality classes alongside imported timber, and the determination, by experiments in utilisation, of the comparative value of the British and foreign timbers respectively. The importance of conducting such work with timber, the origin and history of which is known, and which further represents the average of the quality obtainable in any particular district, will be readily realised.

In the course of this work, other species of Pine which are of economic value, such as the Corsican Pine (*Pinus laricio*), the Maritime Pine (*P. pinaster*), and the Monterey Pine (*P. insignis*) will be studied for comparison with Scots Pine, as opportunities arise.

An investigation planned on the lines described above necessarily involves the accumulation of a mass of observations and measurements, with which it will be difficult to deal if the results are held back until the completion of the enquiry, and the writers have accordingly decided to publish results as they accrue.

WORKING METHODS.

Since this paper forms the first of a series, it will save repetition in subsequent papers if we now give a full description of the working methods adopted. The elementary details given under this head may appear unnecessary to some readers, but as these papers may possibly interest others who have no special knowledge of the methods of scientific Forestry, this full description is given to enable every step in the investigation to be followed. We also consider such a detailed description advisable, as, in view of the little work that has been done on such lines in this country, it may evoke helpful criticisms, which will detect sources of possible error.

For the same reasons the tables in the Appendix give all the calculations in extenso, but in future papers these will be curtailed, and the results summarised as far as possible.

Selection of sample plots. From what has previously been said, the reader will understand that the areas selected for measurement do not necessarily represent the average of the existing stand of timber in the wood which contain those areas. Our aim is not to estimate the volume of the standing timber in a given woodland area, but to ascertain the yield and quality that is actually produced, when conditions approximating as nearly as possible to the laws of silviculture are fulfilled. Owing to the open condition of British woodlands generally, it is no easy matter to find a whole wood of mature timber which does exhibit even and regular distribution of the trees, normal density, complete canopy and a well protected soil. Such conditions may however prevail over small areas of a quarter to half an acre in a wood, the remainder of which exhibits a more open character. We do not select any area for measurement until we have satisfied ourselves that these silvicultural conditions might have been equally well maintained throughout the whole wood with proper management, and that the area is not exceptional in any other respect. The fact that the whole wood does not conform to these conditions does not in any way prejudice the results which accrue from our observations.

Measurements of trees. On selecting a suitable plot for measurement, the area is measured and marked out with string. The trees within this area are measured at breast height, using both a quarter girth tape and callipers, and a numbered label is affixed to each tree as measured to prevent its being taken a second time, and to enable those subsequently selected as samples to be readily found.

Urich's method is employed in this work. The mean diameter of each tree is obtained from two diameters taken at right angles, and the trees are then arranged in half-inch diameter classes. The superficial area of a section of the tree at the level corresponding to each diameter is obtained from tables given in any text book of Forestry for this purpose, and the sum of these basal areas gives the total for the plot (App. Table A, columns 1 to 4). This total basal area divided by the number of trees on the plot gives the mean basal area, and the mean sample tree is one with a diameter corresponding to this mean basal area (App. Table A, columns 5 and 6).

Actual sample trees possessing diameters approaching as nearly as possible to that of the mean sample tree are then selected and felled. The number of actual sample trees felled on any sample plot is limited to one or two by the fact that the work is being carried out on private estates, by the courtesy of their owners.

Volume of sample trees (App. Table C). This is obtained by measuring each tree into 10 foot lengths, and taking diameters over bark at half the length of each log (viz. 5, 15, 25 ft. etc.). The trees are then ringed at the same points, and diameters taken under bark. The sectional areas corresponding to the diameters at these various heights are entered against them, and the total volume of the tree, according to true measure, is then found by the formula:—

$$V = \Sigma s \times h,$$

where 　　 V = volume of the tree.

　　　Σs = the sum of the sectional areas for each log taken at half the length of the log.

　　　h = length of the log.

For purposes of comparison the volume of the sample trees are also found by two other methods.

(1) By taking the diameter at half the total height, finding the corresponding sectional area, and then applying the formula

$$V = Sm \times H,$$

where 　　 V = volume of the tree.

　　　Sm = sectional area of the middle section of the tree.

　　　H = total length of tree.

(2) By the square of quarter girth system of measurement. The quarter girth is taken, over and under bark, at the same heights as the

diameter (viz. at 5, 15, 25 ft. etc.) and the volume of each 10 foot log found by the formula

$$v = \left(\frac{g}{4}\right)^2 \times h,$$

where v = volume of each log.

$\left(\frac{g}{4}\right)^2$ = sectional area at half the height of each log.

h = length of log.

The total volume is then found by

$$V = v^1 + v^2 + v^3 \ldots \text{etc.}$$

where V = total volume of the tree.

$\left.\begin{array}{l} v^1 \\ v^2 \\ v^3 \end{array}\right\}$ = the volumes of the separate logs.

Total volume of the plot (App. Table A). This is now found by the formula

$$V = \frac{v \times S}{s},$$

where V = total volume of plot.

v = volume of actual sample tree or trees.

S = total basal area of plot.

s = basal area of the actual sample tree or trees.

The volume measurements are for timber over 3 inches in diameter and do not include firewood. It was found difficult to get any satisfactory measurements for the latter without the help of a xylometer.

Stem analysis. Whenever a sufficient number of sample trees can be obtained, one of them is used for making an analysis of the stem. If only one sample tree is available from any plot, the conversion of its timber into suitable dimensions for comparison with imported timber, and for future experiments in utilisation, is regarded as of greater importance than stem analysis, which necessitates sawing the logs into lengths of 10 ft. Any tree selected for stem analysis is either a mean sample tree, or possesses dimensions approximating as closely as possible to those of the mean sample tree. The usual method of converting trees for stem analysis involves taking sections at the base, 5 ft., 15 ft.,

25 ft., etc., a plan which results in the butt end of the tree, containing the best timber, being practically wasted. But by taking the sections at ground level, 10 ft., 20 ft., etc., the bottom log of 10 ft. is capable of providing short deals, boards, or sleepers which can be utilised in future work. We have accordingly adopted this method in order to make full use of the material obtained.

The tree before being felled is marked with the cardinal points of the compass, and, as each section is sawn, these points are marked on the surface, so that the relative growth of the timber on the four sides may be studied.

The upper side of each section corresponds with the height at which it is taken (0, 10, 20 ft., etc., as the case may be) and the sections are marked accordingly as soon as cut.

The upper surface of each section is then cleaned to facilitate the subsequent work, which consists of counting the annual rings and measuring the periodic growth for corresponding decades on each section, in order to prepare tables and curves to represent the following items :

(a) *Height Growth*. The annual rings on each section are first counted and from these figures a curve to shew the height increment is plotted (App. Table D and Fig. 5).

(b) *Diameter Growth*. The rings for each decade are then measured on each section along the radii corresponding to the four cardinal points of the compass, and the average radial growth found (App. Table E). In this table an additional column is given to shew the relative growth of the north to south and east to west diameters, as this information may be useful when further trees have been examined.

The average diameters at the end of every decade, as shewn by each section, are obtained by doubling the corresponding average radii (App. Tables E and F).

The diameters of the tree at 5 ft. high at the end of each decade from 5 years onwards (App. Table F, column 3) are averages obtained from the second and fourth columns of the same table $\left(\frac{D_0 + D_{10}}{2}\right)$.
From these figures the curve of diameter increment (Fig. 6) is plotted.

(c) *Growth in Volume* (App. Table G). The volume at the end of each decade is calculated by imagining the tree to be sawn into lengths of 20 ft. Then the diameters of sections No. 2, No. 4, No. 6, and No. 8, given in Table F, represent the middle diameter of each 20 ft. log, and from this the corresponding sectional area is obtained and multiplied

by the length. The Curve of Height Growth (Fig. 5) enables the height of the tree at the end of each decade to be ascertained, and in the case of short lengths, for which there is no middle diameter given in Table F, the average diameter for that particular length is calculated.

The top of the tree is regarded as a cone, the volume of which is calculated by finding the sectional area which corresponds to the diameter at the base of the cone, and multiplying this by one-third of the height.

For instance the tree when 75 years old had a total height according to the curve (Fig. 5) of 80 ft. Table F shews that the diameter at 70 ft. was 2·82 ins. (or 3 ins. for all practical purposes). The volume of the first 60 ft. is obtained from the diameters at 10 ft. (11·34 ins.), 30 ft. (9·96 ins.) and 50 ft. (7·92 ins.). The mean diameter for the odd 10 ft. of timber is found from $\dfrac{D_{60} + D_{70}}{2} = 4\cdot2$ ins. From the diameter at 70 ft. (2·82 ins.) the sectional area at the base of the remaining 10 ft. cone, and the volume of fuel are found.

From these figures the curve shewing the total volume increment (Fig. 7) is plotted.

(*d*) *Summary of Analysis.* By combining the data contained in the height curve and in the table giving the average radii, a graphic representation of the stem analysis is obtained (Fig. 8).

From the data contained in the curves for Height, Diameter, and Volume, a summary is constructed (App. Table H), which shews the periodic increment in volume for each decade.

Heart, Sap and Bark. The proportions in which each of these is present in the tree used for stem analysis is also determined. The volume, over and under bark, having already been obtained (App. Table G), it only remains to measure the heartwood at the same 10 foot levels on the sections (App. Table E), and work out the volume for each 20 foot log in the way already described (App. Table G).

The proportions of heart, sap and bark are also worked out for each sample tree, but, in the absence of sections at every 10 ft., a different method of arriving at the amount of heart present has to be employed. The measurements for over and under bark at 10 foot levels are taken from Table C and plotted on squared paper. No corresponding measurements for the heartwood at these levels are available, because the sample trees were converted into the most suitable log lengths for economic use. But as these logs were sawn up, the heart was at once

measured on the exposed section, two diameters at right angles being taken and the mean recorded. The radii at these levels were then plotted on the squared paper, and the radii of the heartwood at the 10 foot levels corresponding to readings for the sap and bark were then obtained from the heartwood curve (Figs. 1 to 4). From these data the diameter of the heart, and the corresponding sectional area for each 10 foot log is obtained, and the total volume of the heart found by the formula $V = \Sigma s \times h$ as explained above (Table 5).

This method does not of course give quite such accurate results as that employed in the tree used for stem analysis, but in the absence of actual sections at regular intervals the volume of heartwood can only be obtained from measurements taken in this way. The graphs constructed from the above readings represent the proportions of each tissue in a radial longitudinal section of the respective trees, and they further serve to shew the amount of taper.

Form Factors (Table 7). Each sample tree is also used to find the proportion existing between the volume of the tree and that of a cylinder possessing the same diameter as that of the tree at breast height, and of equal length—or in other words the form factor. Before they can be of any service, form factors must of course be obtained from measurements taken on a large number of trees as has been done in Germany, and the values obtained from the few sample trees at our disposal cannot therefore be used to calculate the volume of woods until some hundreds or thousands of calculations for Scots Pine have been worked out.

It would have taken too much time to obtain the measurements of every tree on the sample plots required for this purpose, but on the other hand it was felt that form factors ought to be worked out for the actual sample trees obtained, in spite of their being so few in number, so as to make them yield the fullest information possible.

At all events it makes a beginning, and as time goes on we shall obtain values which, if not sufficiently representative for actual use, will give some indication as to the existence of any correspondence with the form factors given in German Tables.

The method we have adopted gives what is known as the "Artificial form factor," which is derived from the sectional area corresponding to the diameter at breast height, the volume according to true measure, and the height of the tree (see Tables A and C for these measurements). As in the case of the volume measurements, the form factors are only worked out for timber over 3 inches in diameter.

The formula by which the form factor is obtained, is

$$f = \frac{v}{s \times h},$$

where f = form factor.

v = volume of timber.

s = sectional area at breast height.

h = height of the tree.

The relation existing between the diameter at breast height and that at half the height of the tree is also worked out on the same trees, in order to find the percentage ("p") which the latter forms of the diameter at breast height. Once the correspondence between the average values of "p" and "f" has been determined by measurements of a few thousand trees, it is easier to find the form factors by determining "p," than by calculating the volume for each tree, as is required by the former method. It is especially useful in the case of standing trees, as it merely means that the two diameters must be taken at breast height and half the height of the tree respectively, and the percentage worked out by the formula

$$p = \frac{d}{D} \times 100,$$

where p = the percentage.

D = diameter at breast height.

d =   „   half height.

The value of "f" corresponding to the "p" thus found would be obtained from tables to be compiled when sufficient measurements have been worked out.

This method has been used on the continent, and tables shewing the corresponding values of "p" and "f" compiled for Spruce and Silver Fir. We are not aware that such tables have as yet been compiled for Scots Pine.

Quality Classes. In the absence of any recognised quality classes for Scots Pine grown in this country, the sample plots are referred to German quality classes whenever it seems useful to draw comparisons. In doing this we naturally select the German class to which the plot in question appears most nearly related, but this must not be taken to mean that we regard the two as equivalent. On the contrary, as mentioned in the introduction, it will probably be found possible to establish a series of British quality classes as the result of this enquiry.

Conversion of the timber. As soon as all the measurements required for the calculations described above have been taken, the trees which have not been used for stem analysis are sawn into whatever lengths appear, from the shape and regularity of the bole, to be most suitable. These logs are then converted into deals, scantlings, battens, boards, etc., which can be used for the comparative study of the different qualities alongside imported timber, as well as with timber from other species of Pine.

The main idea in converting the timber is to do so with the least possible waste, and to obtain the material most suitable for general economic uses.

When the whole of the timber has been measured after conversion, detailed lists are made up showing the dimensions of each piece, and the total is then expressed in terms of the St Petersburg standard which contains the equivalent of 120 deals $6' \times 11'' \times 3''$ or 165 cubic feet. From this the volume actually obtained is calculated in cubic feet, compared with the volume of the timber in the round before conversion, and the percentage of waste is thus obtained (Table 10).

The short 10 foot lengths obtained from the trees used for stem analysis are also converted into material suitable for subsequent experiments in utilisation.

Soil Analysis. The samples of soil, which are taken for the purpose of analysis, are obtained by a heavy boring instrument with which specimens can be collected down to a depth of 6 ft., provided that no large stones or rock formation are met with. Borings are made in two or three places in each plot, and the samples taken from three levels (viz. 1st foot, 2nd to 4th, and 5th to 6th feet) are placed in three separate bags. These are then analysed both chemically and mechanically at the School of Agriculture, under the direction of Mr L. F. Newman. The method employed by him is that agreed upon by the Agricultural Education Association in 1900[1].

[1] See "Soil Analysis" by A. D. Hall, *Analyst*, Nov. 1900, or "Soils and Agriculture of Norfolk," by L. F. Newman, *Trans. Norfolk and Norwich Nat. Soc.* Vol. IX. p. 349.

II. SAMPLE PLOTS AT WOBURN

THE present paper, which falls under the first section of the investigation, gives the results of measurements taken in woods of Scots Pine on the Duke of Bedford's estate at Woburn, in Bedfordshire.

GENERAL DESCRIPTION OF THE DISTRICT.

Locality. The plots selected for measurement formed part of a large block of woods, covering some 2000 acres, and situated in the parishes of Woburn, Bow Brickhill, Little Brickhill and Aspley Guise. These woods contain a considerable admixture of species, but in the main they are coniferous with Scots Pine predominating. The area on which they stand forms part of an irregularly shaped island of high ground rising out of the broad vale south of Bedford, and separated from the chalk range of the Chiltern Hills on the south-east by a narrow valley of Gault—drained by one of the tributaries of the Ouse. The bulk of the Woburn woods on this area lie between the 300 and 500 ft. contour lines.

Climate. The rainfall in the district is low; the average for the 20 years from 1892 to 1911 was 23¼ ins., according to readings obtained from the Meteorological Office, with a minimum of 19¾ ins. in 1893 and a maximum of 35½ ins. in 1903. In the preceding 20 years the average was about 2 ins. higher. The mean annual temperature for the 20 years ending 1911 was 47·3° Fahr. with a minimum of 46·4° in 1892 and a maximum of 50° in 1911.

Geology. The geological formation of these hills is Lower Greensand with beds of Fuller's Earth, and scattered tracts of Boulder Clay. The soil of the woodland area in question consists mainly of sand.

Soil. Table I gives both the mechanical and chemical analyses of the soil samples taken from each plot. In the mechanical analysis the poor nature of the soil is shewn by the high percentage of sand, especially

coarse sand, while the percentage of clay and silt, in which the constituents of plant food are chiefly found, is small.

The rapid increase in the amount of clay in the deeper levels indicates that the stratum of sand would soon give place to a bed of clay, if borings were continued below 6 ft. The high percentage of organic matter in the first foot is of course due to the thick bed of pine needles, which are very slowly being broken down to form humus.

In the chemical analysis the small amounts of carbonates, potash and phosphorus, and the high percentage of insoluble residue, again shew clearly the poverty of the soil.

TABLE 1.

Soil Analysis.

Description (figures in brackets indicate size of particles)	Plot I				Plot II			
	Depth of borings			Average	Depth of borings			Average
	0—1 ft. °/o	2—4 ft. °/o	5—6 ft. °/o	°/o	0—1 ft. °/o	2—4 ft. °/o	5—6ft. °/o	°/o
Fine gravel (⅛ to 1/75 inch) ...	1·23	1·52	·36	1·04	·97	1·41	Boring prevented by rock or stone formation	1·19
Coarse sand (1/75 to 1/100 inch)	75·09	74·31	61·01	70·14	72·91	73·47		73·19
Fine sand (1/100 to 1/500 inch)	13·12	16·98	27·38	19·16	13·21	14·13		13·67
Coarse silt (1/500 to 1/1000 inch)	1·37	2·04	1·19	1·53	3·12	2·29		2·70
Fine silt (1/1000 to 1/2500 inch)	1·26	1·01	1·49	1·25	1·97	1·23		1·60
Clay (1/2500 inch)	·72	1·55	5·53	2·60	1·94	4·29		3·11
Moisture	1·20	·30	·79	·76	·25	·69		·47
Loss on ignition (organic matter) } ...	8·31	1·76	1·25	3·77	9·13	1·68		5·40
Nitrogen	·123	·056	·014	·064	·124	·019		·071
Carbonates	·08	·00	·04	·04	·21	·05		·13
Potash	·0329	·083	·0616	·0592	·065	·213		·139
Phosphorus pentoxide ...	·032	·038	·027	·032	·039	·044		·041
Iron	2·13	2·89	2·00	2·34	3·01	4·38		3·69
Manganese (*traces only*) ...	—	—	—	—	—	—		—
Lime	·05	·00	·02	·023	·12	·03		·075
Insoluble residue	86·95	94·15	93·26	91·45	86·4	91·11		88·75

GENERAL DESCRIPTION OF THE SAMPLE PLOTS.

Plot No. I. This formed part of a wood of pure Scots Pine, some 50 acres in extent, standing on very undulating ground with rather steep slopes. The trees were 95 years old, had an average height of 88 ft., and the number on the ground was equivalent to 176 trees per acre. The plot measured one quarter of an acre, which was the largest

area we could find without numerous gaps, and was situated on one side of a small valley, from which it extended up the slope. The trend of the valley was N.N.E. to S.S.W., and the slope faced E.S.E. The elevation is 500 ft. The only reason for the selection of this plot was that it was slightly better stocked, and consequently had a more complete canopy, than other portions of the wood. Otherwise the trees were not exceptional in any way. Even so there were several gaps present, which rendered the distribution rather uneven. Originally the trees probably stood thick on the ground, for the sections of the sample trees taken at the base and 10 ft. up are practically free from knots. But the wood is somewhat exposed to the S.W., and as several trees in this neighbourhood have been blown down in recent years, it is probable that the majority of the gaps on the sample plot have been caused by gales.

The trees vary a good deal in size and dimensions, those in the valley exhibiting larger proportions, both in girth and height, than those on the slope. The stems are fairly clean, being practically free of branches up to 45 ft. in height.

One feature, which was very marked in the majority of the trees, was the elliptical shape of the stems in section, the difference between two diameters taken at right angles being often as great as $3\frac{1}{2}$ to 4 ins. The cause of this is difficult to explain, as it appeared to be due neither to the slope of the ground, nor to the direction of the wind. In the measured area the greater axis of the ellipse lay parallel to the direction of the valley below, while on the opposite side of the valley the greater axis lay at right angles to the valley. The point is one requiring more extended observations before any conclusions are drawn.

Plot No. II. This formed part of a wood of about 20 acres standing on ground that was practically level except for a few low banks, at an elevation of 450 ft. above sea level. The trees were 125 years old, but in spite of their being 30 years older than the trees in Plot No. I the average height is identically the same, viz. 88 ft. The stand consisted mainly of Scots Pine, but a few Weymouth Pine and Larch were scattered throughout the whole wood, and it was impossible to obtain an area of any size free of these other species. The plot selected, measuring ·609 of an acre, contained 50 Scots Pine, 2 Weymouth Pine, and 4 Larch, which we have taken as equivalent to 85 Scots Pine per acre. We have arrived at this by regarding the 2 Weymouth Pine as equivalent to 2 Scots Pine, while the Larch have been treated as nonexistent. The former possessed dimensions only a little below those of

the mean sample tree, and the effect of calling them Scots Pine is nil,
so far as the stocking is concerned, for the canopy was fairly open and
all the trees had plenty of head room. And as regards the volume, it
is probable that had these two trees been actually Scots Pine, the total
volume of the plot would have been slightly higher.

The reason for disregarding the 4 Larch was that the volume could
not be measured, and the figures for Scots Pine of similar diameters
could not be taken as equivalents for trees of a different genus. All
four trees possessed diameters considerably below that of the mean
sample tree, viz.:—14½, 15, 16½, and 18½ ins. respectively. The height
was the same as the Pine, 88 ft. This must be borne in mind in
connection with the tables given below, and the plot credited with an
additional 4 Larch trees (equivalent to six trees per acre). The stocking
on this area was very poor and uneven owing to the numerous gaps.
The density was fairly normal in one or two spots but there was no
crowding anywhere. The individual trees varied greatly in their
dimensions, the largest being naturally found on the borders of the
gaps. These were fine trees, very symmetrical in shape with fairly
clean boles.

This plot would not have been selected *per se*, but it was considered
that, in view of the soil and climatic conditions being practically
identical with those of Plot No. I, a study of the results obtainable at
different ages would prove valuable.

SUMMARY OF RESULTS.

Under the various headings which follow, the results of the measure-
ments and calculations are presented in summary form for both plots
together, and the full details will be found in the various tables in the
Appendix, to which reference is made in brackets.

Both the above plots compare most nearly with Quality Class I of
German yield tables for Scots Pine, and in the following pages all com-
parisons with German figures are for this Class. The height of the
Woburn trees in Plot II is much lower, but in other respects the
comparison with Class I is justified.

Stocking. On Plot I (age 95 years) there were 44 trees on the
quarter of an acre, equivalent to 176 per acre (App. Table A). Owing
to gaps the spacing was uneven and the canopy broken. The stocking
is consequently rather lower than it might have been.

On Plot II (age 125 years) there were 52 trees on ·609 acre, equivalent to 85 trees per acre, including the 2 Weymouth Pine and excluding the 4 Larch (App. Table B).

Here the number of gaps was considerable, and the stocking was very low.

The following table enables the stocking to be compared with the figures given in German yield tables for woods of Scots Pine of similar ages.

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TABLE 2.

Stocking.

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Yield tables of	Age	Number of trees per acre	Age	Number of trees per acre
Schwappach[1] ...	95	148	125	101
Weise[2]	95	184	120	140
Schlich[3]	95	185	125	135
Woburn	(I) 95	176	(II) 125	85[4]

The difference in the number of trees per acre between Schwappach and Weise is accounted for by the method of treatment. Schwappach's tables are based on heavy thinnings, and a smaller proportion of trees is left for the final crop, whereby he claims that a larger total return is obtained. Weise's tables are based on light thinnings.

Girth variation. The wide variation in the girth of the trees in both plots is very marked, the difference in diameter between the smallest and largest trees amounting to 13½ ins. (App. Tables A and B).

Acreage Yield. In the following table a summary is given of the yield per acre, based on the measurements of each plot and of the sample trees felled. On Plot No. I three trees of about mean dimensions were felled, of which two were employed as sample trees, and the third for stem analysis. On Plot No. II only one sample tree was felled. Figures taken from German yield tables have also been included for comparison. The detailed measurements for each plot will be found in the Appendix (Tables A, B, C).

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[1] *Die Kiefer*, Adam Schwappach.
[2] *Ertragstafeln für die Kiefer*, Wilhelm Weise.
[3] *Manual of Forestry*, Vol. III., Schlich.
[4] Plus 6 Larch trees per acre which were disregarded.

The outstanding feature of the comparison with the German yield tables in the case of each plot lies in the larger mean diameter, and consequently larger sectional area, possessed by the Woburn trees. In Plot No. I the mean diameter is $10\frac{1}{2}$ °/$_\circ$ greater than that given by Weise, while the sectional area per acre is 19 °/$_\circ$ greater than that of Weise, and 32 °/$_c$ greater than the average of the German figures. The volume compares very favourably, being only 56 cubic ft. less than that of Weise, 617 cubic ft. more than Schlich's total, and 2094 cubic ft. more than Schwappach's total. But in view of the larger sectional area of the Woburn trees, there is actually a considerable falling off in the volume which is of course due to there being eight fewer trees per acre than in Weise's table, and to the average height of the trees being also 6 ft. less. Had the plot been fully stocked there is no doubt that the volume would have considerably exceeded that of Weise.

TABLE 3.

Yield.

According to	Age	Number of trees per acre	Height in feet	Mean diameter in inches	Sectional area per acre in square feet	Timber volume under bark per acre in cubic feet	Timber form factor
Woburn, Plot I	95	176	88	15·4	230·4	8142	·445
Schwappach[1]...	95	148	91	13·4	146·9	6048	·454
Weise[2] ...	95	184	94	13·9	194·1	8198	·454
Schlich[3] ...	95	185	93	13·4	179·5	7525	·45
Woburn, Plot II	125	85[4]	88	21·5	214·6	7980[4]	·465
Schwappach[1]...	125	101	101	16·1	143·4	6522	·45
Weise[2] ...	120	140	100	15·9	194·1	9087	·472
Schlich[3] ...	125	135	104	15·8	182·5	8565	·45

In Plot No. II the Woburn mean diameter is 35 °/$_\circ$ greater than the figure given by Weise, which in this case coincides with the average for the three German readings. But in spite of this, the sectional area per acre is now only 10 °/$_\circ$ greater than Weise, and only 24 °/$_\circ$ greater than the average German sectional area. The total volume compares

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[1] Adam Schwappach, *loc. cit.*   [2] Weise, *loc. cit.*   [3] Schlich, *loc. cit.*
[4] Plus 6 Larch trees disregarded.

badly, being 1107 cubic ft. less than Weise, 585 cubic ft. less than Schlich, and only 1458 cubic ft. more than Schwappach[1]. This again is due to the fewer trees per acre (55 less than Weise) and to the deficiency in height growth (12 ft. less than Weise).

MEASUREMENTS OF SAMPLE TREES.

Volume. Table 4 gives a summary of the measurements of the three sample trees. In order that the different systems of measuring timber may be compared, the results as obtained by true measure and quarter girth are given for each tree. The detailed measurements will be found in the Appendix (Tables A, B and C).

The three trees are all equal as regards the total height, although No. 3 was 30 years older than the other two, but in its timber height it gained a little extra on this account.

As will be seen from the following table, the difference between true and quarter girth measure varies somewhat, and only in tree No. 3 does it work out to the $21\frac{1}{2}$ °/₀ difference which there should be theoretically. The shortage of only $18\frac{1}{2}$ °/₀ on true measure in the case of trees Nos. 1 and 2, is probably accounted for by the elliptical shape of those trees. The two diameters taken at right angles would not necessarily coincide with the maximum and minimum diameters, and had these been taken, the total volume would probably have been a little higher.

The difference between the methods of taking measurements at regular intervals of 10 ft., or of taking one measurement at half the height, is also shewn in the following table. The extent to which the latter method agrees in its results with the former depends upon the regularity of the taper on either side of the middle section as will be seen by comparing Tables 4 and 6. The greater the divergence in taper between the upper and lower halves of the tree, the greater does the difference in the volume obtained by the two systems of measurement become. In tree No. 1, which tapers very differently in the upper and lower halves, the loss in volume by taking diameter at half the height amounts to $5\frac{3}{4}$ °/₀. In tree No. 2, on the other hand, the taper in the two halves is less divergent and the volume obtained by the second method shews a gain of 1 °/₀. Tree No. 3 comes in between these two.

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[1] In comparing the figures with Schwappach the heavy thinnings obtained earlier under his system, as explained on p. 20, must be borne in mind.

TABLE 4. *Summary of Measurements of the Three Sample Trees.*

System of measurement	Sample tree	Age	Height in feet — Total height	Height in feet — Timber height (3" diameter)	Diameter or quarter girth — Description	Diameter or quarter girth — Inches	Area of section — Description	Area of section — Square feet	Volume of timber over 3" diameter — Over bark cubic feet	Volume of timber over 3" diameter — Under bark cubic feet
True measure based on 10 foot lengths	No. 1, Plot I	95	88	80	Diameter at breast height	15·0	Basal area	1·227	49·09	43·45
True measure treating tree as a single log	do.	do.	do.	do.	Diameter at half the height	10·3	Area of middle section (Sm)	0·5787	46·3	Not taken
							Difference, Loss		2·79 (5·7 %)	
Quarter girth measure	do.	do.	do.	do.	Quarter girth at breast height	12·0	Basal area	1·000	40·0	36·5
							Difference, Loss		9·09 (18·5 %)	6·85 (15·8 %)
True measure based on 10 foot lengths	No. 2, Plot I	95	88	80	Diameter at breast height	15·5	Basal area	1·310	50·87	46·30
True measure treating tree as a single log	do.	do.	do.	do.	Diameter at half the height	10·8	Area of middle section (Sm)	0·6362	50·9	Not taken
							Difference, Gain		·53 (1 %)	
Quarter girth measure	do.	do.	do.	do.	Quarter girth at breast height	12·0	Basal area	1·000	41·0	37·9
							Difference, Loss		9·37 (18·6 %)	8·40 (18·1 %)
True measure based on 10 foot lengths	No. 3, Plot II	125	88	83	Diameter at breast height	21·5	Basal area	2·521	103·27	93·76
True measure treating tree as a single log	do.	do.	do.	do.	Diameter at half the height	14·8	Area of middle section (Sm)	1·1946	99·15	Not taken
							Difference, Loss		4·12 (3·9 %)	
Quarter girth measure	do.	do.	do.	do.	Quarter girth at breast height	17·0	Basal area	2·000	81·0	74·5
							Difference, Loss		22·27 (21·5 %)	19·26 (20·5 %)

Heartwood, Sapwood and Bark. In Table 5 the percentage of heart, sap and bark respectively for each sample tree is shewn, and in figs. 1 to 4 the relative proportions of the same tissues, as seen in vertical section from the pith to the periphery through the centre of the tree, are represented.

As explained under "Working Methods" page 12, the only measurements available for the heartwood in the three sample trees were those taken at irregular lengths when the trees were sawn into logs for economic utilisation. These were plotted on squared paper (figs. 1, 2 and 3), and the diameters, on which the volumes of the heart given in this table for trees Nos. 1, 2 and 3 are based, were measured from the curve at the 10 foot levels corresponding to the actual over and under bark measurements.

The figures for tree No. 4, which was analysed as described later, are based on measurements of sections (page 43) and have been added to the table for the sake of comparison, as it happens to have contained a much smaller amount of heart than any of the others. Fig. 4 has been included here for the same reason.

TABLE 5.

Summary shewing volume of Heart, Sap and Bark.

	Tree No. 1, Plot I 95 years old		Tree No. 2, Plot I 95 years old		Tree No. 3, Plot II 125 years old		Tree No. 4, Plot I (stem analysis) 95 years old	
	cub. ft.	per cent.	cub. ft.	per cent.	cub. ft.	per cent.	cub. ft.	per cent.
Heart	17·98	36·6	17·87	35·5	41·92	40·6	10·0	19·4
Sap	25·38	51·7	28·43	56·4	51·84	50·2	38·4	74·4
Bark	5·73	11·7	4·07	8·1	9·51	9·2	3·2	6·2
Total contents	49·09	100	50·37	100	103·27	100	51·6	100

Taper. The effect upon the rapidity of taper resulting from open or close conditions of growth is well shewn in these three sample trees which all attained the same height growth (figs. 1, 2, 3). In the case of trees Nos. 1 and 2 the taper is equivalent to an average decrease in diameter of 1 in. for every 5·4 ft. of height growth, while in tree No. 3 from the poorly stocked plot, the taper is much more rapid, being 1 in. in every 4·1 ft. This decrease in diameter does not proceed uniformly throughout the length of the tree, as the following table, constructed from the graphs, shews. For the first 10 ft. the trees all shew a more or
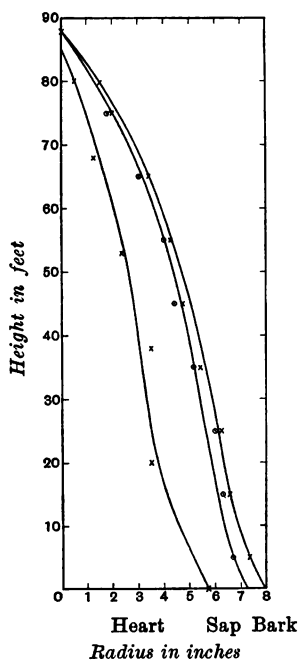
Fig. 1. Tree, No. 1. Graphic representation of a radial section.
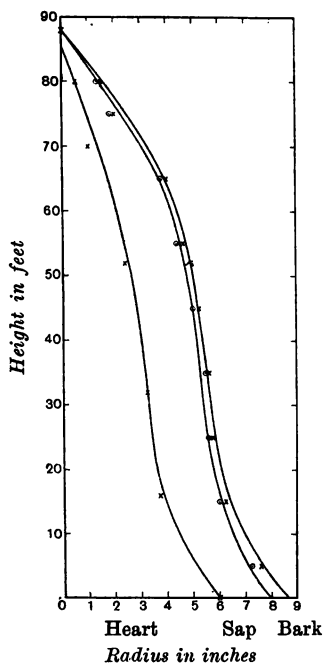
Fig. 2. Tree, No. 2. Graphic representation of a radial section.
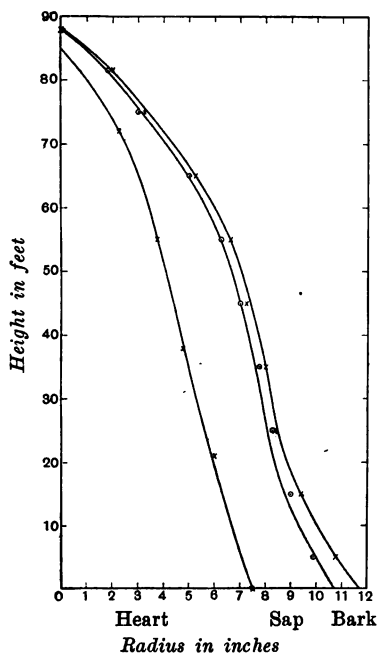
Fig. 3. Tree, No. 3. Graphic representation of a radial section.
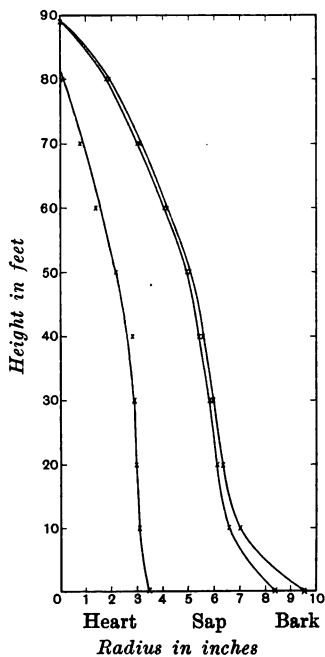
Fig. 4. Tree, No. 4. Graphic representation of a radial section.

TABLE 6.

Details of Taper.

Height of measurement	Tree No. 1, Plot I 95 years old, 176 trees per acre				Tree No. 2, Plot I 95 years old, 176 trees per acre				Tree No. 3, Plot II 125 years old, 85 trees per acre			
	Diameter under bark	Decrease per 10 ft.	Equivalent to decrease of	Equivalent to decrease through 40 ft. of	Diameter under bark	Decrease per 10 ft.	Equivalent to decrease of	Equivalent to decrease through 40 ft. of	Diameter under bark	Decrease per 10 ft.	Equivalent to decrease of	Equivalent to decrease through 40 ft. of
0 feet	14·5"	—	—		16"	—	—		21·3"	—	—	
10 „	12·7"	1·8"	1" in 5·5 ft.		13"	3"	1" in 3·3 ft.		18·7"	2·6"	1" in 3·9 ft.	
20 „	12"	·7"	1" in 14·3 „	1" in 9 ft.	11·6"	1·4"	1" in 7·1 „		17"	1·7"	1" in 5·9 „	1" in 5·9 ft.
30 „	10·9"	1·1"	1" in 9·1 „		10·8"	·8"	1" in 12·5 „	1" in 7 ft.	15·7"	1·3"	1" in 7·7 „	
40 „	10"	·9"	1" in 11·1 „		10·2"	·6"	1" in 16·6 „		14·6"	1·1"	1" in 9 „	
50 „	8·7"	1·3"	1" in 7·7 „		9·5"	·7"	1" in 14·3 „		13·2"	1·4"	1" in 7·1 „	
60 „	7·2"	1·5"	1" in 6·6 „	1" in 5·5 ft.	8·2"	1·3"	1" in 7·7 „		11·4"	1·8"	1" in 5·5 „	1" in 3·8 ft.
70 „	5·5"	1·7"	1" in 5·9 „		6"	2·2"	1" in 4·5 „	1" in 5·3 ft.	8·2"	3·2"	1" in 3·1 „	
80 „	2·7"	2·8"	1" in 3·6 „		2·7"	3·3"	1" in 3·0 „		4"	4·2"	1" in 2·4 „	
88 „	0	2·7"¹	1" in 2·9 „		0	2·7"¹	1" in 2·9 „		0	4"·1	1" in 2·0 „	

¹ Length 8 ft. only.

less rapid taper; in the next 20 to 30 ft. the diameter decreases very slowly, but after that the taper increases steadily in each successive 10 foot length.

Form Factors. Table 7 gives the timber form factors for the three trees, from which it will be seen that the average practically agrees with the German figure for trees of the same height. The corresponding value of "p" is also given[1].

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TABLE 7.

Form Factors.

</div>

Tree	Form factor for true volume	Value of "p" for true volume
No. 1	·454	64·6
No. 2	·437	68·4
No. 3	·465	68·1
Average	·452	67·0
Form factor from German yield tables	·453	—

<div align="center">

STEM ANALYSIS. TREE No. 4 (PLOT I).

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There was no tree available on Plot II for stem analysis, and the one now described was felled on Plot I. The dimensions of this tree were practically the same as those of the mean sample tree, its total height being 89 ft., and the diameter and quarter girth at breast height 15 ins. and 13½ ins. respectively.

The tree, which stood in a fairly well stocked portion of the plot, was well grown with a straight clean stem but with rather thick bark at the base. It appeared in all respects to be a fair average specimen for the plot, though after felling the heart was seen to be less strongly developed than in either of the sample trees.

Height Growth. The curve of height growth (fig. 5), plotted from measurements given in Table D of the Appendix, shews that the tree

[1] v. ante, p. 14, under Working Methods.

made a rapid start and maintained a fairly even growth throughout its
life. The following table (No. 8) enables a comparison in this respect
to be made with trees of the same age according to the measurements
given in the German yield tables. From this it will be noticed that
the Woburn tree attained a height which was 2 ft. below Schwappach's
tree, and 5 ft. below that of Weise.
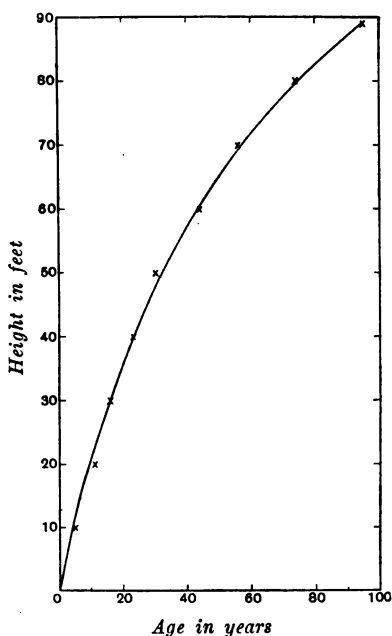
Fig. 5.   Tree No. 4.   Curve of the Height Increment.

TABLE 8.

*Tree No. 4.   Comparison of the Growth in Height with figures
from German yield tables.*

Yield tables by	Age	Number of trees per acre	Height
Schwappach ...	95 years	148	91 feet
Weise	95 ,,	184	94 ,,
Schlich	95 ,,	185	93 ,,
Woburn tree, No. 4	95 ,,	176	89 ,,

Diameter Growth. In fig. 6 the curve *A* illustrates the growth in diameter of this tree, based on the measurements given in Table F in the Appendix. Curve *B* has been drawn from measurements for sample trees of the same age in Germany according to the yield tables previously mentioned. This curve represents the average of the figures given by the three authorities. From this it is seen that, while the German trees did not reach a diameter of 5 ins. until they were about 32 years old, the Woburn tree started better, attained this diameter seven years earlier, and kept the lead throughout its life.
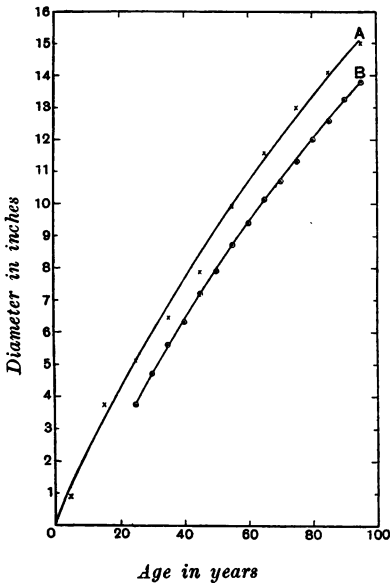
Fig. 6. Tree, No. 4. Curve of the Diameter Increment at 5 ft. from the ground.
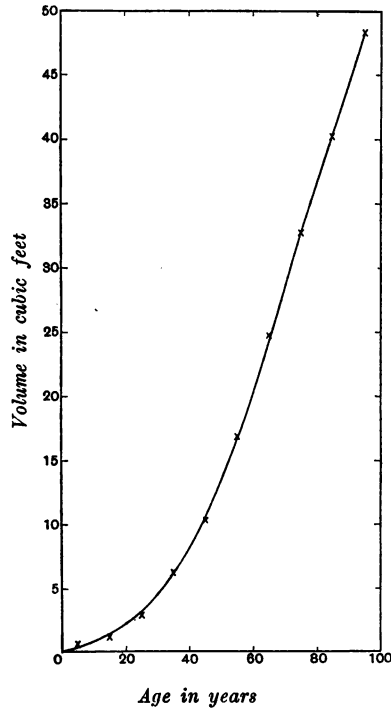
Fig. 7. Tree, No. 4. Curve of the Volume Increment (under bark).

Volume. Fig. 7 gives a curve to shew the increment in volume, which was plotted from the measurements etc. contained in Table G of the Appendix. From this it is seen that for the first 25 years or so the tree made slow progress in volume, but afterwards picked up rapidly, and maintained a steady rate of increase, which was only beginning to fall off at the time when the tree was felled.

Table 9 gives a summary of the volumes of timber, over 3 ins. diameter, and fuel in the bole at different ages, and also of the proportions of heartwood, sapwood and bark in the tree when felled.

TABLE 9.

Summary of the Volumes at Different Ages.

Age			Fuel, cubic feet	Timber, cubic feet	Total, cubic feet	Percentage
5 years	...	...	·1	0·0	·1	
15 ,,	...	...	·3	0·8	1·1	
25 ,,	...	...	·2	2·8	3·0	
35 ,,	...	...	·4	6·0	6·4	
45 ,,	...	...	·2	10·1	10·3	
55 ,,	...	...	·1	16·6	16·7	
65 ,,	...	...	·4	24·2	24·6	
75 ,,	...	...	·1	32·6	32·7	
85 ,,	...	...	0	40·2	40·2	
95 ,, under bark			·2	48·2	48·4	
95 ,, over bark			·2	51·4	51·6	
95 years	...	...	volume of heartwood		10·0	19·4
95 ,,	...	...	,, sapwood		38·4	74·4
95 ,,	...	...	,, bark		3·2	6·2
			Total		51·6	100

Graphic Representation of the Analysis. Fig. 8 represents graphically a vertical section of one half of the tree, in which the growth during each decade is shewn alternately shaded or white. The figure illustrates clearly the gradual tendency of the tree to decrease the amount of taper and become more cylindrical—the general effect when trees are grown under close conditions.

Conversion of the Logs. The three sample trees were converted into planks, deals, battens, scantlings, boards and lathwood, only timber possessing a diameter above 5 ins. being used for this purpose. The tops, with diameter below 5 ins., were naturally full of large knots and valueless except for firewood.

It would serve no useful purpose to give the full specification of the converted material obtained from each tree, but the following list gives the equivalent in running feet of 1″ × 1″, and in cubic feet :—

Tree No. 1.—4233½ ft. of 1″ × 1″   29·4 cub. ft.
,,   No. 2.—4156   ,,   ,,   28·86   ,,
,,   No. 3.—9110¾   ,,   ,,   63·25   ,,

Table 10 gives the volumes of each tree before and after conversion, and the waste which took place during the process.

As the quarter girth method of measurement is the one used in actual practice for ascertaining the volume in the round, any estimates
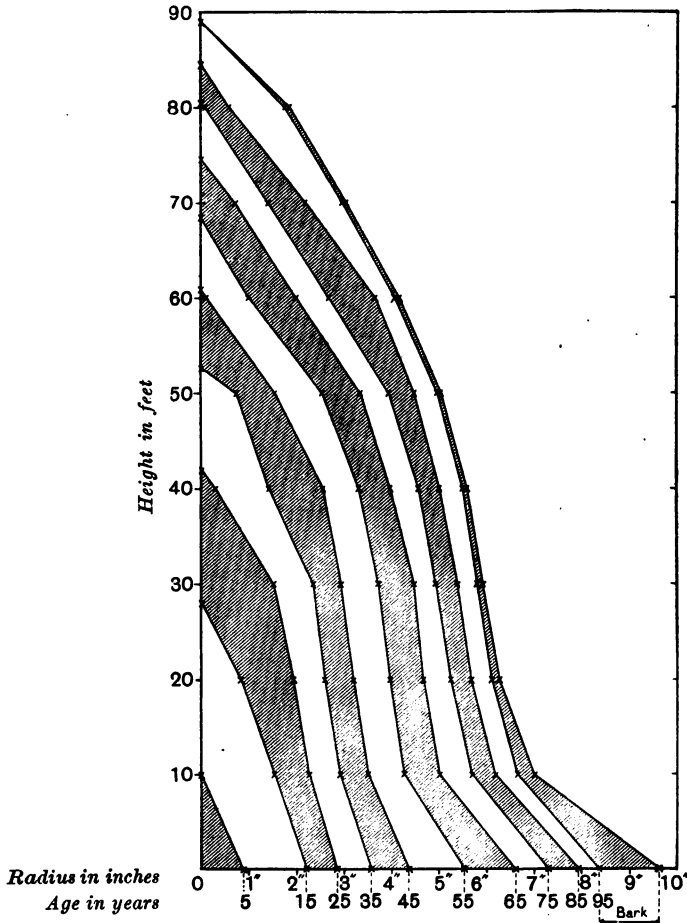
Fig. 8.   Tree, No. 4.   Graphic representation of the Stem Analysis
(vertical section of one half of the tree).   Alternate decades
shaded for the sake of clearness.

made in estate saw mills of the waste in timber will naturally be based on the volume obtained by this method.   The volume in the round of these sample trees, according to both true measure and quarter girth measure, has therefore been given in the table, in order that the percentage of waste in each case may be compared.

TABLE 10.

Waste in Conversion.

| | Tree, No. 1 | | | Tree, No. 2 | | | Tree, No. 3 | | |
| | | Volume under bark | | | Volume under bark | | | Volume under bark | |
	Length	According to true measure	According to quarter girth method	Length	According to true measure	According to quarter girth method	Length	According to true measure	According to quarter girth method
		cubic feet	cubic feet		cubic feet	cubic feet		cubic feet	cubic feet
Measurements in the round ...	80 feet	43·35	36·5	80 feet	46·30	37·9	83 feet	93·76	74·5
Less "top" under 5″ diameter not converted	12 ,,	1·33	1·0	10 ,,	·77	·7	11 ,,	1·75	·9
Total before conversion	68 feet	42·02	35·5	70 feet	45·53	37·2	72 feet	92·01	73·6
Converted material	—	29·4	29·4	—	28·86	28·86	—	63·25	63·25
Waste in conversion	—	12·62	6·1	—	16·67	8·34	—	28·76	10·35
Percentage	—	30 %	17 %	—	36½ %	22½ %	—	31 %	14 %

The extent of the waste of course depends upon the class of material into which a tree is converted, but, as this investigation proceeds, we hope to obtain fairly reliable data as to the allowance. which must ·be made for waste, according to the main assortments of converted material.

In the present case, for an assorted specification of planks, deals, boards, etc., the average percentage of waste for the three trees works out to

$32\frac{1}{2}$ $°/_{o}$ on the volume according to true measure

and $17\frac{3}{4}$ $°/_{o}$ „ „ „ quarter girth measure.

Finally Table 11 shews the equivalent volume of converted material per acre obtainable in the form of an assortment of planks, deals, boards, etc., similar to that obtained from the sample trees.

TABLE 11.

Equivalent Volume of Converted Material per acre.

	Age	Volume of converted material per sample tree	Number of trees per acre	Equivalent volume of converted material per acre	Equivalent in terms of St Petersburg Standard
Plot I	95 years	29·13[1] cub. ft.	176	5127 cub. ft.	31 standards
Plot II	125 ,,	63·25 ,,	85	5376 ,,	$32\frac{1}{2}$,,

The assortment, classification and grading of the converted material will be dealt with under Part II of this enquiry, when sufficient material from sample plots in other districts has been collected.

[1] Average of two trees.

APPENDIX

TABLE A. *Plot I. Back Wood, Little Bow Brickhill, Woburn. Aspect, E.S.E., Elevation 500 ft. Area ¼ acre. Age 95 years. Average Height 88 ft. Soil, Sand.*

Diameter at breast height	Number of trees	Plot, Basal area		Mean sample tree		Real sample trees felled				Volume of plot, cub. ft.
		Detailed sq. ft.	Total sq. ft.	Average basal area sq. ft.	Equivalent diameter at breast height, inches	Tree Number	Diameter, breast height, inches	Basal area, sq. ft.	Volume under bark, cub. ft.	
11 inches	4	2·640								
11½ ,,	2	1·442								
12 ,,	2	1·560								
12½ ,,	1	0·852								
13 ,,	3	2·763								
13½ ,,	4	3·976								
14 ,,	3	3·207								
15 ,,	3	3·681		1·309 (i.e. 57·601/44)	15·4	No. 1	15·0	1·227	43·35	
15½ ,,	5	6·550				No. 2	15·5	1·310	46·30	
16 ,,	2	2·792								
16½ ,,	2	2·968								
17 ,,	4	6·304								
17½ ,,	1	1·670								
18 ,,	2	3·534								
18½ ,,	1	1·866								
19 ,,	2	3·936								
20 ,,	1	2·181								
21 ,,	1	2·405								
24½ ,,	1	3·274								
	44		57·601					2·537	89·65	2035·5
Per acre =	176		230·4						per acre =	8142·0

$$V = \frac{89·65 \times 57·601}{2·537} = 2035·5 \text{ cubic feet.}$$

3—2

TABLE B. *Plot II. Bow Brickhill Park, Woburn. Aspect, level ground. Elevation 450 ft. Area ·609 acre. Age 125 years. Average Height 88 ft. Soil, Sand.*

Diameter at breast height	Number of trees	Plot, Basal area — Detailed sq. ft.	Plot, Basal area — Total sq. ft.	Mean sample tree — Average basal area, sq. ft.	Mean sample tree — Equivalent diameter at breast height, inches	Real sample tree felled — Tree Number	Real sample tree felled — Diameter breast height, inches	Real sample tree felled — Basal area, sq. ft.	Real sample tree felled — Volume under bark, cub. ft.	Volume of plot, cub. ft.
16 inches	1	1·396								
17 ,,	1	1·576								
17½ ,,	1	1·670								
18 ,,	2	3·534								
18½ ,,	3	5·598								
19 ,,	5	9·840								
19½ ,,	1	2·073								
20 ,,	8	17·448								
20½ ,,	1	2·292								
21 ,,	2	4·810								
21½ ,,	9	22·689								
22 ,,	5	13·195								
22½ ,,	2	5·522								
23½ ,,	1	3·012								
24 ,,	3	9·423								
24½ ,,	1	3·274								
26 ,,	4	14·748								
26½ ,,	1	3·830								
29½ ,,	1	4·746								
	52[1]		130·676	2·513 $\left(\text{i.e. } \frac{130·676}{52}\right)$	21·45	No. 3	21·5	2·521	93·76	4860·0
Per acre =	85[1]		214·6				per acre =	2·521	93·76	7980·0

$$V = \frac{93·76 \times 130·676}{2·521} = 4860 \text{ cubic feet.}$$

[1] Plus 4 Larch which were disregarded; equivalent to 6 trees per acre. The 52 trees include 2 Weymouth Pine which were counted as equivalent to 2 Scots Pine.

TABLE D.

Tree, No. 4. Plot I. Analysis of stem from sections taken at 10 foot lengths.

	Height of section	Number of rings	Number of years taken to reach height of that section
Section 1	0 feet	95	0 years
,, 2	10 ,,	90	5 ,,
,, 3	20 ,,	84	11 ,,
,, 4	30 ,,	79	16 ,,
,, 5	40 ,,	72	23 ,,
,, 6	50 ,,	65	30 ,,
,, 7	60 ,,	51	44 ,,
,, 8	70 ,,	39	56 ,,
,, 9	80 ,,	21	74 ,,
Top = 9 feet long	89 ,,	0	95 ,,

TABLE C. Sample trees. Volume according to true measure.

Height at which measurements were taken	Sample tree, No. 1, Plot I Height (up to 3 inches diameter) = 80 ft.				Sample tree, No. 2, Plot I Height (up to 3 inches diameter) = 80 ft.				Sample tree, No. 3, Plot II Height (up to 3 inches diameter) = 83 ft.			
	Over bark		Under bark		Over bark		Under bark		Over bark		Under bark	
	Diameter, inches	Sectional area, sq. ft.	Diameter, inches	Sectional area, sq. ft.	Diameter, inches	Sectional area, sq. ft.	Diameter, inches	Sectional area, sq. ft.	Diameter, inches	Sectional area, sq. ft.	Diameter, inches	Sectional area, sq. ft.
5 feet	14¾	1·1865	13½	·9941	15¼	1·2685	14½	1·1467	21½	2·5212	19¾	2·1274
15 ,,	13¼	·9576	12¼	·8859	12¾	·8523	12	·7854	18¾	1·9175	18	1·7671
25 ,,	12½	·8523	12	·7854	11½	·7214	11½	·7214	16¾	1·5303	16¼	1·4849
35 ,,	11¼	·6903	10¾	·6303	11¼	·6903	10¾	·6303	16	1·3963	15½	1·3104
45 ,,	9¼	·4923	8¾	·4176	10¼	·6014	10	·5454	14¾	1·1467	14	1·0690
55 ,,	8½	·3941	8	·3491	9¼	·4667	8¾	·4173	13¾	·9576	12½	·8523
65 ,,	6¾	·2485	6	·1963	8	·3491	7½	·3066	10½	·6014	10	·5454
75 ,,	4	·0873	3¾	·0767	4	·0873	3¾	·0766	6½	·2304	6	·1963
										10·3014		9·3528
81¼ ,,		4·9089		4·3354		5·0370		4·6297	4	·0873	3¾	·0767
Volume calculated by formula V = Σs × h												

Sample tree, No. 1, Plot I:

V over bark = 4·9089 × 10 = **49·089** cub. ft.
V under bark = 4·3354 × 10 = **43·354** cub. ft.
Difference due to bark = **5·735** cub. ft. = **(11·7 °/₀)**

Sample tree, No. 2, Plot I:

V over bark = 5·037 × 10 = **50·37** cub. ft.
V under bark = 4·6297 × 10 = **46·297** cub. ft.
Difference due to bark = **4·073** cub. ft. = **(8·06 °/₀)**

Sample tree, No. 3, Plot II:

V over bark = (10·3014 × 10) + (·0873 × 3) = **103·276** cub. ft.
V under bark = (9·3528 × 10) + (·0767 × 3) = **93·758** cub. ft.
Difference due to bark = **9·518** cub. ft. = **(9·2 °/₀)**

Height at which measurements were taken	Sample tree, No. 1				Sample tree, No. 2				Sample tree, No. 3			
	Over bark		Under bark		Over bark		Under bark		Over bark		Under bark	
	Quarter girth, inches	Sectional area = $\left(\frac{g}{4}\right)^2$, sq. ft.	Quarter girth, inches	Sectional area = $\left(\frac{g}{4}\right)^2$, sq. ft.	Quarter girth, inches	Sectional area = $\left(\frac{g}{4}\right)^2$, sq. ft.	Quarter girth, inches	Sectional area = $\left(\frac{g}{4}\right)^2$, sq. ft.	Quarter girth, inches	Sectional area = $\left(\frac{g}{4}\right)^2$, sq. ft.	Quarter girth, inches	Sectional area = $\left(\frac{g}{4}\right)^2$, sq. ft.
5 feet	12	1·0	11¼	·88	12	1·0	11¼	·88	17	2·0	15½	1·67
15 ,,	10¼	·72	10	·69	10	·69	9¼	·66	14¼	1·46	14	1·36
25 ,,	9½	·63	9¼	·59	9½	·63	9¼	·59	13¼	1·22	13	1·17
35 ,,	9	·56	8¾	·53	9	·56	8¼	·53	12¼	1·08	12¼	1·04
45 ,,	8¼	·47	7¾	·42	8¼	·47	8	·44	11¼	·88	11	·84
55 ,,	6¾	·32	6½	·29	7½	·39	7¼	·36	10¼	·80	10½	·77
65 ,,	5½	·23	5¼	·19	6½	·29	6¼	·27	8¼	·47	8	·44
75 ,,	3½	·07	3	·06	3¼	·07	3	·06	5	·17	4½	·14
81½ ,,	—	4·00	—	3·65	—	4·1	—	3·79	8¼	8·08	3	7·43
										·07		·06

Volume calculated by formula $V = \Sigma s \times h$

Sample tree No. 1:
V over bark = 4 × 10 = **40** cub. ft.
V under bark = 3·65 × 10 = **36·5** cub. ft.

Sample tree No. 2:
V over bark = 4·1 × 10 = **41** cub. ft.
V under bark = 3·79 × 10 = **37·9** cub. ft.

Sample tree No. 3:
V over bark = (8·08 × 10) + (·07 × 8) = **81** cub. ft.
V under bark = (7·43 × 10) + (·06 × 3) = **74·5** cub. ft.

Volume calculated by formula $V = Sm \times H$

Sample tree No. 1:
Diameter at 40 ft. = 10·3 inches
Sm = ·5787 sq. ft.
V over bark = ·5787 × 80 = **46·3** cub. ft. = (**8·7**% loss)

Sample tree No. 2:
Diameter at 40 ft. = 10·8 inches
Sm = ·6362 sq. ft.
V over bark = ·6362 × 80 = **50·9** cub. ft. = (**1**% gain)

Sample tree No. 3:
Diameter at 41½ ft. = 14·8 inches
Sm = 1·1946 sq. ft.
V over bark = 1·1946 × 83 = **99·152** cub. ft. = (**3·9**% loss)

TABLE E. *Tree, No. 4. Measurements of Radii at Different Ages and Heights.*

Section Number and height	Rings	Radii in inches					Average number of rings included	Radii of Heartwood in inches					Average total diameters	Difference in growth of $N+S$ and $E+W$ diameters	
		N	S	E	W	Average		N	S	E	W	Average		$N+S$	$E+W$
I at foot of tree	Total over bark	9·3	10·4	8·9	9·8	9·6							19·2	+1·0	
	95 rings	7·75	8·86	8·64	8·2	8·36							16·72	+·08	
	85 ,,	7·4	8·4	7·82	7·9	7·88							15·76	+·3	+·23
	75 ,,	6·98	7·74	7·07	7·35	7·28							14·56	+·49	
	65 ,,	6·4	7·04	6·24	6·71	6·60							13·2	+·51	
	55 ,,	5·5	5·83	5·17	5·65	5·54							11·08	+·27	
	45 ,,	4·13	4·69	3·97	4·58	4·34	34	3·2	3·3	3·2	4·4	3·52	8·68	+·20	
	35 ,,	3·39	3·82		3·81	3·55							7·10	+·18	
	25 ,,	2·8	2·98	2·6	3·0	2·84							5·68	+·13	
	15 ,,	2·18	2·33	2·03	2·35	2·22							4·44	+·09	
	5 ,,	0·95	0·9	0·8	0·96	0·90							1·80		
II at 10 feet high	Total over bark	7·7	6·6	7·1	6·8	7·0							14·0	+·4	
	90 rings	7·25	6·26	6·7	6·4	6·65							13·3	+·41	
	80 ,,	6·71	5·88	6·12	6·05	6·19							12·88	+·42	
	70 ,,	6·13	5·38	5·63	5·53	5·67							11·34	+·35	
	60 ,,	5·37	4·74	5·1	4·84	5·01							10·02	+·17	
	50 ,,	4·61	4·07	4·29	4·22	4·29	33	3·2	2·94	3·3	3·0	3·11	8·58	+·17	
	40 ,,	3·77	3·32	3·53	3·4	3·5							7·0	+·16	
	30 ,,	3·14	2·78	2·98	2·76	2·91							5·82	+·18	
	20 ,,	2·41	2·21	2·27	2·13	2·25							4·5	+·22	
	10 ,,	1·67	1·59	1·53	1·49	1·57							3·14	+·24	
III at 20 feet high	Total over bark	6·5	6·1	6·4	6·2	6·3							12·6	—	—
	84 rings	6·3	5·94	6·26	6·08	6·14							12·28	+·03	+·1
	74 ,,	5·88	5·53	5·69	5·69	5·7							11·40	—	+·08
	64 ,,	5·38	5·09	5·36	5·19	5·25							10·50	+·11	+·08
	54 ,,	4·73	4·59	4·58	4·63	4·63							9·26	—	—
	44 ,,	3·97	3·78	3·9	4·01	3·91	30	2·65	2·92	3·26	2·99	2·95	7·82	—	+·16
	34 ,,	3·23	3·11	3·26	3·22	3·20							6·40	—	+·14
	24 ,,	2·58	2·6	2·69	2·57	2·60							5·20	+·03	+·08
	14 ,,	1·94	1·92	1·97	1·86	1·92							3·84	+·00	
	4 ,,	·89	·41	·66	·75								1·34		

TABLE E.—(continued). Tree, No. 4. Measurements of ...

Section Number and height	Rings	Radii in inches					Radii of Heartwood in inches						Average total diameters	Difference in growth of N+S and E+W diameters	
		N	S	E	W	Average	Average number of rings included	N	S	E	W	Average		N+S	E+W
IV at 30 feet high	Total over bark	6·3	5·9	5·7	5·7	5·9							11·8	+·8	
	70 rings	6·17	5·86	5·69	5·53	5·81							11·62	+·81	
	60 ,,	5·63	5·46	5·37	5·17	5·41							10·82	+·55	
	50 ,,	5·27	5·07	4·8	4·8	4·98	28	2·79	2·77	2·83	3·08	2·87	9·96	+·74	
	40 ,,	4·62	4·43	4·26	4·44	4·44							8·88	+·35	
	30 ,,	3·88	3·68	3·59	3·71	3·71							7·42	+·26	
	20 ,,	3·01	2·77	2·88	3·05	2·93							5·86		+·15
	10 ,,	2·4	2·25	2·32	2·4	2·34							4·68		+·07
	0 ,,	1·53	1·5	1·52	1·5	1·51							3·02	+·01	
V at 40 feet high	Total over bark	5·9	5·2	5·7	5·4	5·55							11·1	—	
	72 rings	5·82	5·07	5·65	5·32	5·46							10·92		+·08
	62 ,,	5·43	4·64	5·11	4·84	5·0							10·0	+·12	
	52 ,,	4·94	4·24	4·64	4·37	4·55	26	3·09	2·55	2·8	2·78	2·8	9·10	+·17	
	42 ,,	4·21	3·72	4·11	3·87	3·98							7·96		+·05
	32 ,,	3·56	3·04	3·4	3·2	3·3							6·6		
	22 ,,	2·72	2·34	2·59	2·5	2·54							5·08	+·07	+·03
	12 ,,	1·96	1·7	1·81	1·78	1·81							3·62		+·02
	2 ,,	·32	·3	·32	·32	·31							·62		
VI at 50 feet high	Total over bark	5·2	4·9	5·3	4·7	5·0							10·0	+·1	+·11
	65 rings	5·13	4·79	5·28	4·6	4·95							9·9	+·04	+·18
	55 ,,	4·63	4·36	4·69	4·16	4·45							8·92	+·14	+·52
	45 ,,	4·06	3·82	4·15	3·84	3·96	22	2·32	2·1	2·1	2·71	2·17	7·92		
	35 ,,	3·44	3·18	3·38	3·42	3·37							6·74		
	25 ,,	2·52	2·29	2·48	2·85[1]	2·43							4·86		+·03
	15 ,,	1·6	1·46	1·6	1·49	1·54							3·08		+·07
	5 ,,	·79	·68	·81	·73	·75							1·50		

[1] Due to influence of knot, disregarded in finding average.

TABLE E—(continued).   *Tree, No. 4.   Measurements of Radii at Different Ages and Heights.*

Section Number and height	Rings	Radii in inches					Average number of rings included	Radii of Heartwood in inches					Average total diameters	Difference in growth of N+S and E+W diameters	
		N	S	E	W	Average		N	S	E	W	Average		N+S	E+W
VII at 60 feet high	Total over bark	4·4	3·7	4·7	3·7	4·1							8·2		+·15
	51 rings	4·39	3·68	4·66	3·6	4·08							8·16		+·19
	41 ,,	3·86	3·0	3·91	3·07	3·47							6·94		+·15
	31 ,,	3·13	2·3	3·15	2·49	2·77	15	1·75	1·16	1·47	1·29	1·42	5·54		+·21
	21 ,,	2·87	1·64	2·21	1·88	2·02							4·04		+·08
	11 ,,	1·14	·85	1·0	1·0	1·0							2·0	+·05	+·01
	1 ,,	·13	·1	·09	·09	·1							·2		
VIII at 70 feet high	Total over bark	3·5	2·6	3·3	2·7	3·0							6·0	+·1	
	39 rings	3·45	2·55	3·28	2·68	2·99							5·98	+·04	+·04
	29 ,,	2·54	1·87	2·39	1·96	2·19	10	0·87	0·6	0·8	0·69	0·75	4·38	+·06	
	19 ,,	1·61	1·19	1·53	1·31	1·41							2·82	—	
	9 ,,	·81	·63	·77	·67	·72							1·44		—
IX at 80 feet high	Total over bark	1·97	1·73	1·81	1·80	1·83							3·6	+·09	
	21 rings	1·94	1·69	1·78	1·76	1·79							3·58	+·09	
	11 ,,	·69	·62	·62	·62	·64	1	·09	·09	·08	·09	·09	1·28	+·07	
	1 ,,	·09	·09	·08	·09	·09							·18	+·01	

TABLE F.

Tree, No. 4. Diameters at Different Ages and Heights. Summarised from Table E.

Age	0 feet Section 1	5 feet[1]	10 feet Section 2	20 feet Section 3	30 feet Section 4	40 feet Section 5	50 feet Section 6	60 feet Section 7	70 feet Section 8	80 feet Section 9
				Average diameters in inches at						
95 years over bark	19·2	16·6	14·0	12·6	11·8	11·1	10·0	8·2	6·0	3·6
95 years under bark	16·72	15·0	13·3	12·28	11·62	10·92	9·9	8·16	5·98	3·58
85 years ...	15·76	14·1	12·38	11·4	10·82	10·0	8·92	6·94	4·38	1·28
75 ,, ...	14·56	13·0	11·34	10·5	9·96	9·1	7·92	5·54	2·82	·18
65 ,, ...	13·2	11·6	10·02	9·26	8·88	7·96	6·74	4·04	1·44	
55 ,, ...	11·08	9·85	8·58	7·82	7·42	6·6	4·86	2·0		
45 ,, ...	8·68	7·85	7·0	6·4	5·86	5·08	3·08	·2		
35 ,, ...	7·1	6·45	5·82	5·2	4·68	3·62	1·5			
25 ,, ...	5·68	5·1	4·5	3·84	3·02	·62				
15 ,, ...	4·44	3·75	3·14	1·64						
5 ,, ...	1·8	·90								
				Average diameters of Heart						
95 years ...	7·04	6·63	6·22	5·9	5·74	5·6	4·34	2·84	1·5	·18

[1] Diameters at 5 feet obtained by $\left(\dfrac{D_0 + D_{10}}{2}\right)$.

TABLE G.   *Tree, No. 4.   Calculation of the Volume at different ages—and of the Volume of the Heartwood.*

Age	Number of log	Diameter in inches	Basal area in sq. ft.	Length of log in ft.	Volume of Timber, cub. ft.	Volume of Fuel, cub. ft.	Total volume, Timber and Fuel, cub. ft.
95 years (whole tree over bark)	No. 1	14·0	1·07	20	**21·4**		
	2	11·8	·76	20	**15·2**		
	3	10·0	·54	20	**10·9**		
	4	6·0	·19	20	**3·9**		
							51·4
	5	3·6	·07	9/3		·2	·2
				89 ft.			**51·6**
95 years (whole tree under bark)	1	13·3	·96	20	**19·2**		
	2	11·6	·73	20	**14·6**		
	3	9·9	·53	20	**10·6**		
	4	5·9	·19	20	**3·8**		
							48·2
	5	3·58	·07	9/3		·2	·2
				89 ft.			**48·4**
85 years	1	12·4	·84	20	**16·8**		
	2	10·8	·64	20	**12·8**		
	3	8·9	·43	20	**8·6**		
	4	4·4	·10	20	**2·0**		
							40·2
	5	1·3	·01	5/3		·02	0
				85 ft.			**40·2**
75 years	1	11·3	·70	20	**14·0**		
	2	10·0	·54	20	**10·8**		
	3	7·9	·34	20	**6·8**		
	4	4·2	·10	10	**1·0**		
							32·6
	5	2·8	·04	10/3		·1	·1
				80 ft.			**32·7**
65 years	1	10·0	·54	20	**10·8**		
	2	8·9	·43	20	**8·6**		
	3	6·7	·24	20	**4·8**		
							24·2
	4	2·7	·04	10		·4	
	5	1·4	·01	5/3		·02	·4
				75 ft.			**24·6**

TABLE G—(*continued*).

Age	Number of log	Diameter in inches	Basal area in sq. ft.	Length of log in ft.	Volume of Timber, cub. ft.	Volume of Fuel, cub. ft.	Total volume, Timber and Fuel, cub. ft.
55 years	No. 1	8·6	·40	20	**8·0**		
	2	7·4	·30	20	**6·0**		
	3	4·9	·13	20	**2·6**		
							16·6
	4	2·0	·022	9/3		·1	·1
				69 ft.			**16·7**
45 years	1	7·0	·27	20	**5·4**		
	2	5·9	·19	20	**3·8**		
	3	4·1	·09	10	**·9**		
							10·1
	4	3·1	·05	11/3		·2	·2
				61 ft.			**10·3**
35 years	1	5·8	·18	20	**3·6**		
	2	4·7	·12	20	**2·4**		
							6·0
	3	2·6	·036	10		·36	
	4	1·5	·012	3/3		·01	·4
				53 ft.			**6·4**
25 years	1	4·5	·11	20	**2·2**		
	2	3·4	·06	10	**·6**		
							2·8
	3	3·0	·05	12/3		·2	·2
				42 ft.			**3·0**
15 years	1	3·8	·08	10	**0·8**		**0·8**
	2	2·4	·03	10		**0·3**	
	3	1·6	·014	8/3		·04	·3
				28 ft.			**1·1**
5 years	1	1·8	·018	10/3		**·06**	·1

VOLUME OF HEARTWOOD

Age	Number of log	Diameter in inches	Basal area in sq. ft.	Length of log in ft.	Volume of Timber, cub. ft.	Volume of Fuel, cub. ft.	Total volume, Timber and Fuel, cub. ft.
95 years	1	6·22	·21	20	**4·2**		
	2	5·74	·18	20	**3·6**		
	3	4·34	·10	20	**2·0**		
	4	1·5	·01	20	**0·2**		
				80 ft.	**10·0**		

TABLE H.

Tree, No. 4. Summary of data from the several curves.

Age of tree	Height in feet	Diameters without bark at 5 feet high in inches	Volume without bark in cubic feet	Periodic volume increment for every decade in cubic feet
0	—	—	—	} 0·8 cubic feet
10 years	20 feet	2·4 inches	0·8 cubic feet	1·5 ,,
20 ,,	36 ,,	4·2 ,,	2·3 ,,	2·3 ,,
30 ,,	48 ,,	6·0 ,,	4·6 ,,	3·9 ,,
40 ,,	57 ,,	7·6 ,,	8·5 ,,	5·0 ,,
50 ,,	64 ,,	9·2 ,,	13·5 ,,	6·5 ,,
60 ,,	72 ,,	10·6 ,,	20·0 ,,	9·0 ,,
70 ,,	77 ,,	12·0 ,,	29·0 ,,	9·7 ,,
80 ,,	82 ,,	13·1 ,,	38·7 ,,	6·5 ,,
90 ,,	87 ,,	14·4 ,,	45·2 ,,	3·2 (for 5 years)
95 ,,	89 ,,	15·0 ,,	48·4 ,,	
			Total	48·4 cubic feet

University of Cambridge
School of Forestry

The Production and Utilisation of Pine Timber in Great Britain

Part I.   Production

No. 2.   Sample Plot of Scots Pine at King's Lynn

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ACKNOWLEDGMENTS

CONTENTS

ERRATA

Bulletin, No. 1.   Sample Plots at Woburn.

Page 23.   Last column of Table 4—

Read 43·35 *instead of* 43·45 *for volume of Tree No.* 1 *under bark.*

Page 24.   5th line from bottom—

Read 5·7 ft. *instead of* 5·4 ft.

SAMPLE PLOT OF SCOTS PINE AT KING'S LYNN

General Description of the District.

Locality. The plot selected for measurement formed part of a block of woods, some 450 acres in extent, situated in the parishes of Gaywood, Mintlyn and Bawsey.

The woods consist mainly of mixtures, only about 10 acres of the ground carrying pure Scots Pine.

The general elevation is low, the highest point being less than 125 ft. above sea level.

Climate. The rainfall in the district is comparatively low; according to readings obtained from the Meteorological Office, the average for the 20 years from 1892 to 1911 was 26 ins., with a minimum of 22 inches in 1898, and a maximum of $35\frac{1}{2}$ ins. in 1903. In the preceding 20 years the average was about $2\frac{3}{4}$ ins. higher. The mean annual temperature for the 20 years ending 1911 was $48\frac{1}{2}°$ Fahr., with a minimum of $46\frac{1}{2}°$ Fahr. in 1892, and a maximum of $50°$ Fahr. in 1911.

Geology. The geological formation of the district is Lower Greensand, with occasional scattered patches of Oxford Clay and Boulder Clay.

The soil of the woodland area in question is mainly sand.

Soil. Table 1 gives the mechanical and chemical analyses of the soil samples taken from the plot. A comparison of these figures with those for Woburn[1] shews that although in general composition the soil of the two places is very similar, the King's Lynn soil is the poorer. It contains a higher proportion of sand, while the percentage of clay and silt is little more than half that found in the Woburn plots.

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[1] Burdon and Long, *The Production and Utilisation of Scots Pine in Great Britain.* No. 1, Sample plots at Woburn, p. 17.

There is considerable depth of sand, but hard "pan," impenetrable by roots, often occurs at various depths, a condition not found at Woburn. In the chemical analysis the percentage of carbonates is a little better, but the insoluble residue shews a slight increase.

The table shews a lower percentage of iron than was expected, but the occurrence of the hard "pan" is very irregular, and the plot borings, while they shewed indications of its existence, did not actually come on to it. It is probable that a greater number of borings would shew that there is in reality a good deal more iron in this soil than at Woburn.

TABLE 1.

Soil Analysis.

Description (figures in brackets indicate size of particles)	Depth of borings			Average %
	0—1 ft. %	2—4 ft. %	5—6 ft. %	
Fine gravel ($\frac{1}{4}$ to $\frac{1}{25}$ inch) ...	·16	·15	·13	·15
Coarse sand ($\frac{1}{25}$ to $\frac{1}{100}$ inch)	62·18	63·62	59·24	61·68
Fine sand ($\frac{1}{100}$ to $\frac{1}{500}$ inch)	27·40	27·33	33·67	29·46
Coarse silt ($\frac{1}{500}$ to $\frac{1}{2500}$ inch)	·64	1·07	·65	·78
Fine silt ($\frac{1}{2500}$ to $\frac{1}{5000}$ inch)	·50	·87	·48	·62
Clay ($\frac{1}{5000}$ inch)	·56	2·26	3·75	2·19
Moisture	1·31	·67	·25	·74
Loss on ignition (organic matter) ...	8·21	3·03	1·42	4·22
Nitrogen	·123	·047	·014	·061
Carbonates	·33	·58	·27	·39
Potash	·065	·058	·095	·073
Phosphorus pentoxide ...	·057	·050	·029	·045
Iron	·069	·368	·568	·335
Manganese (*traces only*) ...	—	—	—	—
Lime	·18	·32	·15	·22
Insoluble residue	89·50	89·60	95·75	91·62

GENERAL DESCRIPTION OF THE SAMPLE PLOT.

The plot formed part of a wood of pure Scots Pine, about 10 acres in extent, standing on ground that was practically level except for a few small rises and dips, at an elevation of between 25 and 50 ft. above sea level. In general character the wood comes into a lower class than those at Woburn, and it was felt that measurements obtained from it would be useful in this comparative study.

The trees were 91 years old, had an average height of 65 feet, and the number on the ground was equivalent to 216 trees per acre. They

varied considerably in their dimensions, and three size classes, large, medium and small, could be roughly distinguished. Owing to the numerous gaps, and also to the irregular distribution of the different sizes through the wood, it was impossible to get a single plot of even ¼ acre which could be regarded as representative.

The three sizes were arranged to some extent in groups, a very open group consisting chiefly of large trees in one place, another group over-crowded in places containing a large proportion of small trees, and elsewhere trees mainly of medium size with moderate stocking but many gaps. This irregularity was partly due to want of proper manage-ment in the past, trees having been removed somewhat freely in some portions of the wood while in other places they had not been sufficiently thinned. Generally speaking the boles of the trees were only free of branches up to about 25 ft. to 30 ft. When the trees were originally planted, they undoubtedly stood too far apart, for the butt ends of both sample trees after conversion shewed large knots running from the centre nearly to the periphery. Six of these knots, possessing a diameter of about 1 inch, appeared in the basal section of one tree.

The writers decided that the only fair way to treat this wood was to measure three different areas, the relative extent of each area being based upon the proportion in which the trees of different size were present. The relative numerical proportions of large, medium and small trees were estimated to be 1 : 5 : 4 respectively, and the areas measured were accordingly $\frac{1}{20}$ acre large trees, ¼ acre medium trees and ⅕ acre small trees, making a total of ½ acre.

Summary of Results.

Full tables of measurements, similar to those given for the sample plots at Woburn, have been prepared, but as the same methods have been employed, there is no need to do more than summarise the results.

In the following summary, comparisons are made with German figures for Quality Class II, with which the plot most nearly agrees, except as regards the height of the trees.

Stocking. The number of trees on the three areas measured was as follows :—

$\frac{1}{20}$ acre	10 trees, equivalent to 200 trees per acre		
¼ acre	50 ,, ,,	200 ,, ,,
⅕ acre	48 ,, ,,	240 ,, ,,
½ acre	108 ,, ,,	216 ,, ,,

The stocking, as Table 2 shews, is identical with that given by Weise for stands one year younger.

TABLE 2.

Acreage Yield.

According to	Age	Number of trees per acre	Height in feet	Mean diameter in inches	Sectional area per acre in square feet	Timber volume under bark per acre in cubic feet	Timber form factor	"*p*"
Schwappach [1]...	90	196	76	11·5	140·8	4930	·459	—
Weise [2] ...	90	216	79	12·2	175·9	6120	·440	—
Schlich [3] ...	90	300	68	9·6	152·0	4740	·460	—
King's Lynn	91	216	65	13·3	208·6	6030	·494	74·3

Girth Variation. The difference in diameter between the smallest and largest trees amounted to 15 inches, a very wide variation, due to the irregular distribution of the trees. Most gaps occurred on the ¼ acre and the difference in diameter was 10½ inches, while on the 1/20 acre where the gaps were least abundant the difference in diameter was 8½ inches. On the ⅛ acre the conditions were intermediate, and the difference was 9½ inches.

Acreage Yield. Table 2 gives a summary of the yield per acre, based on the measurements of the plot and of two sample trees which were felled.

The fact is again brought out here, as at Woburn[4], that the volume per acre would have considerably exceeded that given for Quality Class II in German Yield tables for trees of similar age, had the trees been more evenly distributed. Taking the highest German readings as given by Weise, the mean diameter of the King's Lynn trees is 9 °/₀ greater, and the sectional area per acre 18½ °/₀ greater. The average sectional area of the three German readings is 156·2 sq. ft., and compared with this, the King's Lynn figure shews an increase of 33½ °/₀.

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[1] *Die Kiefer*, Adam Schwappach. In drawing comparisons with Schwappach's figures the heavy thinnings obtained earlier under his system, as explained in Bulletin, No. 1, p. 20, must be borne in mind.

[2] *Ertragstafeln für die Kiefer*, Wilhelm Weise.

[3] *Manual of Forestry*, Vol. III., Schlich.

[4] Burdon and Long, *loc. cit.*, p. 21.

TABLE 3. *Summary of Measurements of the Two Sample Trees.*

System of measurement	Sample tree	Age	Height in feet		Diameter or quarter girth		Area of section		Volume of timber over 3" diameter	
			Total height	Timber height (3" diameter)	Description	Inches	Description	Square feet	Over bark cubic feet	Under bark cubic feet
True measure based on 10 foot lengths	No. 1	91	65	60	Diameter at breast height	13·5	Basal area	·9941	31·542	28·541
True measure treating tree as a single log	do.	do.	do.	do.	Diameter at half the height	10·0	Area of middle section (Sm)	·5454	32·724	29·538
							Difference, Gain		1·182 (3¾%)	·997 (3½%)
Quarter girth measure based on 10 foot lengths	do.	do.	do.	do.	Quarter girth at breast height	10·5	Basal area	·76	24·5	22·4
							Difference, Loss		7·04 (22¼%)	6·14 (21½%)
True measure based on 10 foot lengths	No. 2	91	65	60	Diameter at breast height	13·75	Basal area	1·0312	33·562	30·012
True measure treating tree as a single log	do.	do.	do.	do.	Diameter at half the height	10·25	Area of middle section (Sm)	·5731	34·386	29·538
							Difference, Gain		·824 (2½%) *Loss*	·474 (1½%)
Quarter girth measure based on 10 foot lengths	do.	do.	do.	do.	Quarter girth at breast height	10·8	Basal area	·81	26·4	23·4
							Difference, Loss		7·16 (21¼%)	6·61 (22%)

In volume the King's Lynn wood is 90 cubic feet less than Weise's total, 1100 cubic feet more than Schwappach's, and 1290 cubic feet more than Schlich's.

The height of the King's Lynn trees is 14 ft. lower than that of Weise's trees, which accounts for the fact that the volume is lower in spite of the larger sectional area.

MEASUREMENTS OF SAMPLE TREES.

Volume.   Table 3 gives a summary of the measurements of the two trees as obtained by three methods.   The difference between quarter girth and true measure here works out to within 1 $°/_o$ of the theoretical difference of 21$\frac{1}{2}$ $°/_o$, while by measuring the whole log at half the height, there is a slight gain in three out of the four cases.

Heartwood, Sapwood and Bark.   The proportion of heartwood was only worked out for sample tree No. 2 which was used for stem analysis.   This is graphically represented in fig. 4, page 12, and the volumes of heart, sap, and bark are given in Table 5.   Tree No. 1 was almost identical with this tree as regards the sap and bark, and the one graph serves for both.

Taper.   Both trees were taken from fairly well stocked portions of the plot, and the degree of taper is very similar.   The decrease in diameter was rather more rapid and less regular in tree No. 1, but in each case the total was equivalent to a decrease of 1 inch in every 4·9 ft. of height.   In this respect the trees were not so good as those from Plot I at Woburn in spite of the stocking being higher.

TABLE 4.

Form Factors.

Tree	Form factor for true volume	Value of "p" for true volume
No. 1 No. 2	·488 ·501	74·0 74·6
Average	·494	74·3
Average Form Factor for trees of same height from German Field Tables	·464	—

Form Factors. The average timber form factor for the two trees worked out to ·494, which, as Table 4 shews, is considerably higher than the average value for trees of the same height in Germany.

Stem Analysis. Tree No. 2.

This tree, the dimensions of which have already been given in Table 3, carried a strong growth of side branches on the top 15 ft., and no readings of any value were obtainable from the sections above 50 ft. up.

It was unfortunately impossible to deal with the sections as soon as they were cut, and by the time the measurements were made, the sections had become dry, and some were badly cracked.

Height. Fig. 1 shews the curve of height growth, which, after a slow start, proceeded regularly at a moderate rate. The total height was 3 ft. less than that given by Schlich, and 14 ft. less than that given by Weise (Table 2).

Diameter. In fig. 2, curve *A* represents the growth in diameter of this tree, and curve *B* the average of figures given by Schwappach, Weise and Schlich for trees of the same age in Germany. From this it

TABLE 5.

Summary of the Volumes at Different Ages.

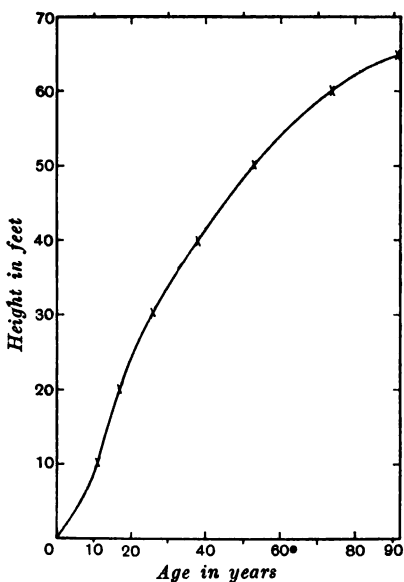| Age	Fuel, cubic feet	Timber, cubic feet	Total, cubic feet	Percentage
11 years	·2	0·0	0·2	
21 ,, ...	·2	1·0	1·2	
31 ,, ...	·3	2·8	3·1	
41 ,, ...	·3	6·1	6·4	
51 ,, ...	·8	9·0	9·8	
61 ,, ...	·4	14·0	14·4	
71 ,, ...	·1	19·0	19·1	
81 ,, ...	·4	22·6	23·0	
91 ,, under bark	·1	25·6	25·7	
91 ,, over bark	·1	27·8	27·9	
91 years	volume of heartwood		7·8	28 °/o
91 ,, ...	,, sapwood		17·9	64 °/o
91 ,, ...	,, bark		2·2	8 °/o
		Total	27·9	100·0

Fig. 1.   Tree No. 2.   Curve of the
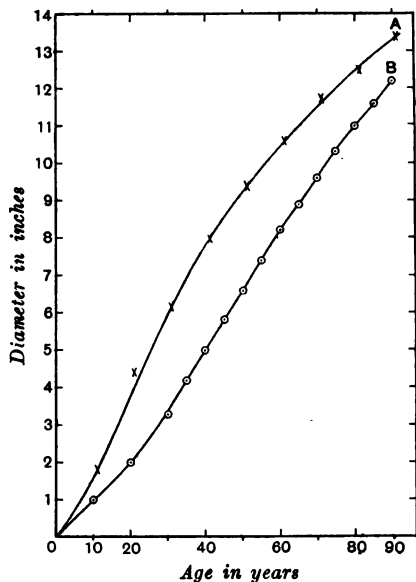Height Increment.

Fig. 2.   Tree No. 2.   Curve of the
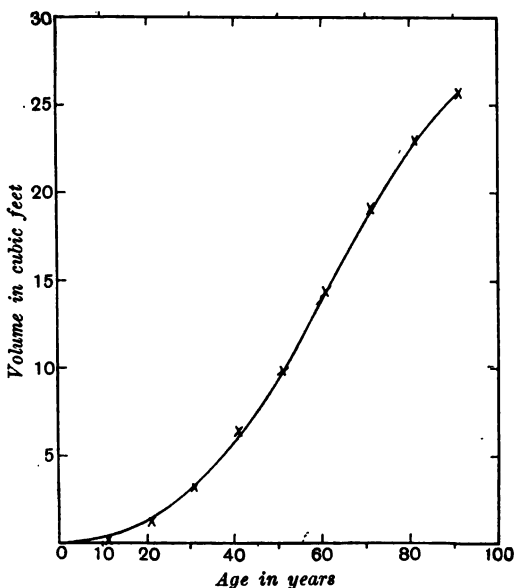Diameter Increment at 5 ft. from
the ground.

Fig. 3.   Tree No. 2.   Curve of the Volume
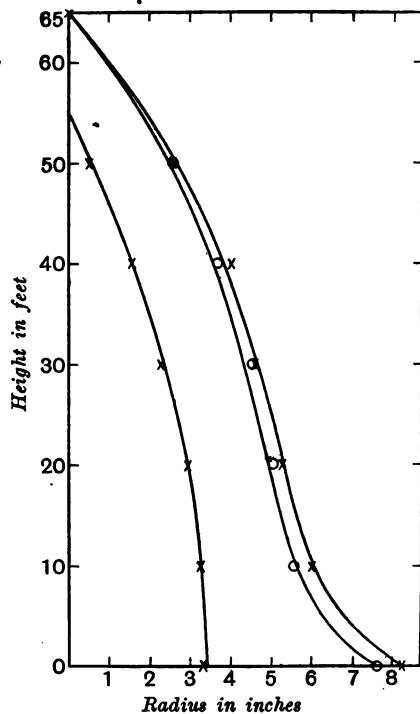Increment (under bark).

Fig. 4.   Tree No. 2.   Graphic repre-
sentation of a radial section based on
measurements of sections taken at
10 ft. intervals.

is seen that the King's Lynn tree made a better start, reached a diameter of 5 inches 14 years earlier than the German trees, and of 8 inches 18 years earlier. After this time however the diametrical growth began to fall off slightly, and at 12 inches, the average limit reached by the German trees of this age, it was only about 13 years ahead. The subsequent increment during the final 13 years of its life was only 1 inch.

Volume. In fig. 3 the increment in volume is represented, while Table 5 gives a summary of the volumes of timber over 3 inches diameter, and of fuel in the bole, at different ages. The proportions of heartwood, sapwood and bark in the mature tree are also given, and fig. 4 gives a graphic representation of the tree in radial section.

These shew that the volume increment was very slow, until the tree was almost 40 years old, after which it increased moderately fast until 70 years was reached. It then began to fall off, and in the last 10 years only added $2\frac{3}{4}$ cub. ft.

TABLE 6.

Summary of Increment Values.

Age of tree	Height		Diameter without bark at 5 feet		Volume without bark	
	Total in feet	Periodic increment in feet	Total in inches	Periodic increment in inches	Total in cubic feet	Periodic increment in cubic feet
0	0		0		0	
		9		1·6		0·5
10 years	9		1·6		0·5	
		15		2·2		1·0
20 ,,	24		3·8		1·5	
		10		2·2		1·5
30 ,,	34		6·0		3·0	
		7		1·8		2·7
40 ,,	41		7·8		5·7	
		7		1·4		3·7
50 ,,	48		9·2		9·4	
		6		1·2		4·6
60 ,,	54		10·4		14·0	
		5		1·1		4·5
70 ,,	59		11·5		18·5	
		3		1·0		4·0
80 ,, (11 years)	62		12·5		22·5	
		3		0·9		3·2
91 ,,	65		13·4		25·7	
Totals	—	65	—	13·4	—	25·7

On comparing the total volume in Table 5 with that given for the same tree in Table 3 it will be noticed that the volume based on stem analysis is about 5½ cub. ft. less. As explained above the sections used for stem analysis were dry, while the measurements summarised in
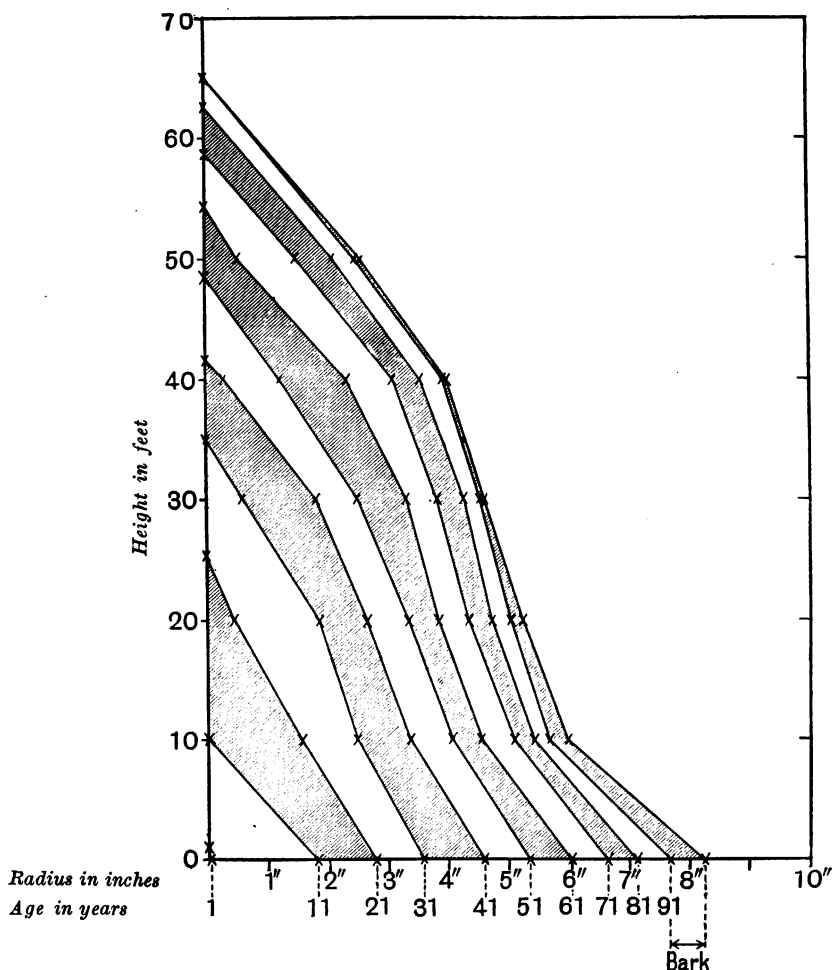

Fig. 5. Tree No. 2. Graphic representation of the Stem Analysis (vertical section of one half of the tree). Alternate decades shaded for the sake of clearness.

Table 3 were taken on the log as soon as it was felled. A large proportion of the loss is consequently due to the shrinkage of the sections. In addition to this the different method of calculating the volume in the stem analysis might easily account for any remaining difference.

Summary of the Stem Analysis. Fig. 5 gives a graphic representation of a vertical section of one half of the tree, in which the decline in growth during the last two decades should be noticed. This is also expressed in Table 6 which gives a summary of the increment values.

It will be seen that the volume increment culminated at about 60 years of age, or some twenty years earlier than tree No. 4 at Woburn. Up to this point it had practically kept pace with the Woburn tree in respect of diametrical growth, but had fallen far behind in height growth, the difference at this age being 18 feet.

CONVERSION. TREE NO. 1.

As tree No. 2 was utilised for stem analysis, the above tree was the only one available for economic conversion. This was sawn into an assortment of battens, scantlings, boards, etc., neither planks nor deals being obtainable from this size of log. Only timber up to 5 ins. diameter was used for the purpose, the knotty "top" being discarded.

The equivalent of the material obtained in running feet of $1'' \times 1''$, and in cubic feet, was 2720½ feet $1'' \times 1''$ (18·9 cubic feet). Table 7

TABLE 7.
Waste in Conversion.

	Sample tree No. 1		
	Length	Volume under bark	
		According to true measure	According to quarter girth measure
	feet	cubic feet	cubic feet
Measurements in the round ...	65	28·5	22·4
Less "top" under 5″ diameter not converted	15	1·0	0·9
Total before conversion ...	50	27·5	21·5
Converted material	—	18·9	18·9
Waste in conversion	—	8·6	2·6
Percentage	—	31 %	12 %

gives the volumes before and after conversion, and the waste which took place during the process, according to both true and quarter girth measures.

Finally Table 8 shews the equivalent volume of converted material per acre, on the basis of the above mentioned assortment of battens, boards, etc., obtained from one sample tree.

TABLE 8.

Equivalent Volume of Converted Material per acre.

Age	Volume of converted material per sample tree	Number of trees per acre	Equivalent volume of con- verted material per acre	Equivalent in terms of St Petersburg Standard
91 years	18·9 cub. ft.	216	4082 cub. ft.	24½ standards